NEW SIGNAL PROCESSING TECHNIQUES FOR IMPROVED RELIABILITY OF IMPEDANCE CARDIOGRAPHY

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ABSTRACT

Different techniques have been developed for parameter extraction and segmentation of the impedance cardiogram for improved reliability and precision of beat-to-beat determination of systolic time intervals, stroke volume and related cardiac indices. The solutions presented here improve upon previous techniques by; (1) substantially reducing jitter in the localization of events within the cardiac cycle; (2) providing exact determination of signal amplitudes even in the presence of artifacts and interference signals; and (3) eliminating the influence of respiratory signal modulation on parameter extraction.

INTRODUCTION

In spite of its theoretical potential, impedance cardiography has not yet found adequate practical application, mainly due to shortcomings of available systems, especially with regard to the implemented signal processing techniques. Improved reliability - a prerequisite for broad clinical acceptance - could be achieved by the development of new signal processing techniques that are able to detect and analyze the signal events in the cardiac cycle with increased precision. This would provide for more reliable, non-invasive beat-to-beat determinations of systolic time intervals, stroke volume, and related cardiac indices.

Three major problems exist in the detection of cardiac events from available signals: (1) localization of slow wave onsets and weak maxima or minima; (2) determination of signal amplitudes; and (3) removal of respiratory signal modulation. Previously used threshold detection, simple maximum look-up, and averaging techniques are inadequate as they show a large amount of jitter in localization and amplitude determination and beat-to-beat variations and transient responses. In contract, we have solved the localization problem by analyzing the momentary frequency of signal and have determined signal amplitudes and removed respiratory signal modulation vsias correlation analysis technique.

METHODS

The determination of stroke volume from the impedance cardiogram requires the measurement of the maximum rate of impedance change (dZ/dt_{max}) during the ejection period. Difficulties arise as neither the maximum of the dZ/dt signal nor the baseline are easily determined. As can be seen from Figure 1, interference prevents simple detection of the maxima, and the unstable waveform makes it impossible to find a reliable zero

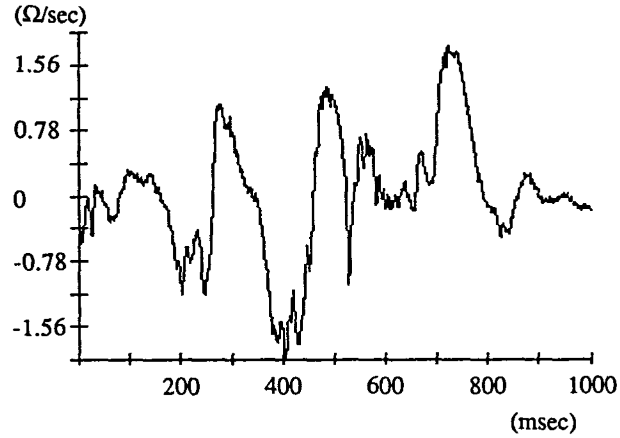

Figure 1. Impedance cardiogram (dZ/dt) of subject under exercise

reference. The problem was solved by correlation analysis (Nagel, 1984). Through coherent averaging, a template of the impedance signal was calculated representing one cardiac cycle with improved signal/noise ratio enabling easy determination of the mean dZ/dt_{max}. The autocorrelation function of the template for zero delay represents its mean power. Calculating the crosscorrelation function between template and current dZ/dt gives the crosspower function. As crosscorrelation eliminates the influence of artifacts and noise, the maxima indicate the ratio between actual and mean dZ/dt_{max}. The advantage of this technique is that the information about the dZ/dt amplitude is based on a whole dZ/dt complex thus being independent from superimposed noise and not requiring the determination of the baseline in the disturbed signal.

Figure 2 demonstrates the performance of this matched filter approach. Scaling the analyzed signal to the amplitude of the template provided an excellent match, i.e., the precision of amplitude determination was apparently not influenced by the peak deformation due to noise.

The same crosscorrelation analysis was also used for the detection of aortic opening and closing in the impedance signal, essentially reducing the jitter in systolic time intervals relative to previously used techniques. Templates were obtained by breaking the previously described whole cardiac cycle pattern down into segments representing the single events. Sometimes, however, no distinctive pattern could be found for the aortic opening. Even complementary signals like the

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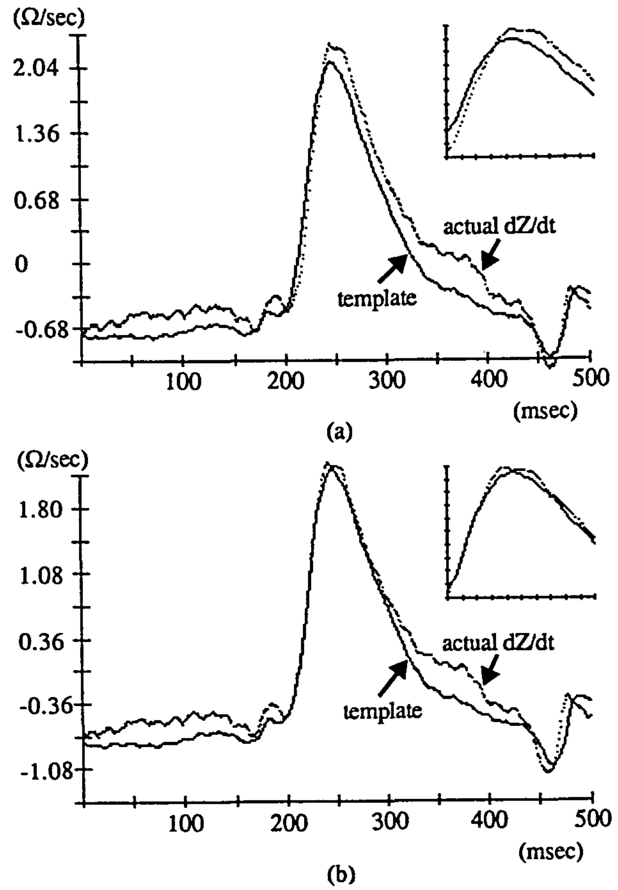

Figure 2. Maximum detection (a) and matched filter analysis (b) of the impedance cardiogram. In (a) the maxima of the template and actual impedance cardiogram are aligned. In (b) position and amplitude are adjusted by matched filtering.

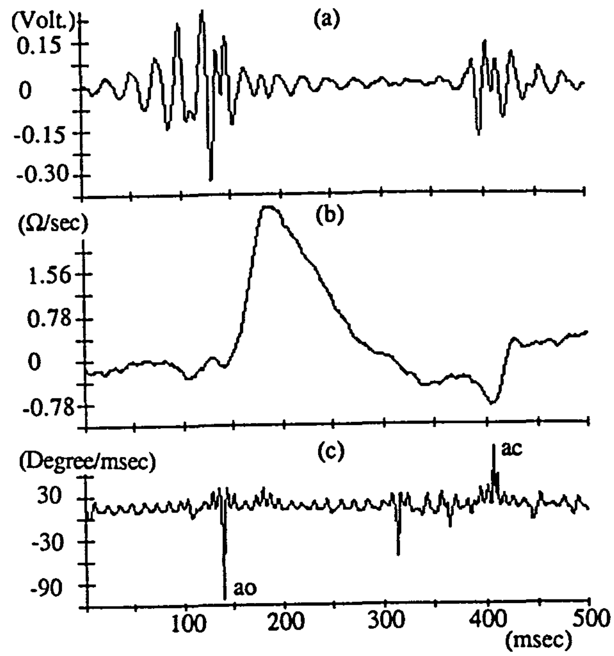

Figure 3. Phonocardiogram (a), dZ/dt (b), and momentary frequency (c) indicating aortic opening (ao) and closing (ac).

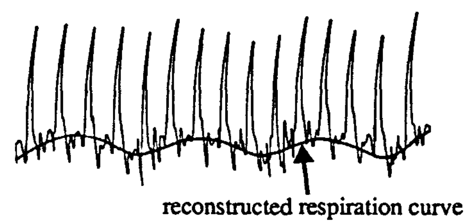

Figure 4. Respiratory modulation of the impedance cardiogram (dZ/dt).

phonocardiogram do not provide enough structure for the detection of aortic opening by any pattern recognition process. For these cases a detection algorithm was developed that is based on the analysis of the momentary signal frequency (Bodecker, 1982; Nagel, 1986).

As the onset of any event within a biological signal source, such as the opening of a heart valve, leads to a fundamental change of signal mode, it can be assumed that the instantaneous frequency shows distinct marks both at the onset and offset of the event. From Figure 3 it can be seen that both aortic opening and closing are easily detected from the instantaneous frequency, whereas the original signal is much more difficult to analyze. The same technique was also successfully tested for the detection of Q-wave onset in the ECG, as required for the determination of systolic time intervals.

Respiratory modulation of dZ/dt has a direct influence on the magnitude of the calculated stroke volume if no compensation is provided. Averaging seems to eliminate modulation but also covers any short time variation of stroke volume. With the above described correlation analysis it was possible to obtain fixed reference points on the dZ/dt signal. Based on these sampling points, the low frequent respiration curve was reconstructed and used for compensation of dZ/dt (Figure 4). So far, the character of the modulation is not yet exactly known, and just additive superposition is assumed as a first approximation. Further work is in progress to evaluate a possible multiplicative component by spectral decomposition and to assess the impact of the described techniques on impedance cardiography.

ACKNOWLEDGEMENTS

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